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Vegetative structure and species composition of mangroves along the Mumbai coast, Maharashtra, India

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HIGHLIGHTS

- Diversity, vegetative structure and regeneration status of Mangroves along the Mumbai coast, India was studied.
- A total of 10 mangrove species belonging to 5 families and 8 genera were recorded.
- Avicennia marina was found to have higher habitat suitability than others.
- The study highlights the need to preserve the species diversity of Mumbai mangroves.

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ABSTRACT

The mangroves of Mumbai coast have witnessed significant degradation in recent times. Although studies on mangrove floristics of Mumbai coast started in 1905, no comprehensive efforts have been made to assess the vegetative structure and regeneration pattern. Considering these facts, field surveys were carried out in 8 selected sites in Mumbai coast during August 2015 to May 2016, using quadrat method. A total of 10 species belonging to 5 families and 8 genera were recorded. The average tree density was recorded to be 635 individuals ha^{-1} varying from 325 to 708, whereas basal area of mangroves was found to be 11.16 m^2 ha^{-1}, varying between 5.60 and 28.26 m^2 ha^{-1}. *Avicennia marina* constituted 50% of the Important Value Index, 78% of tree density, 71% of basal area and 75.63% of the total juvenile density, indicating the dominance of this species in the mangroves of Mumbai coast. The low values of diversity indices (H' =0.90) and complexity index (Ic=3.77) indicate the low species diversity and poor structural development of mangroves along the Mumbai coast. It indicates that immediate conservation and management measures should be taken to preserve the mangrove species diversity of Mumbai coast.

1. Introduction

Mangrove forests are trees, shrubs and ferns that occupy the inter-tidal areas between land and sea of tropical and subtropical regions (Clough, 2013; Tomlinson, 1986). The majority of the mangrove forests are found between latitudes of 30°N and 30°S. They are among the most productive ecosystems and play a significant role in mitigation of increasing atmospheric carbon dioxide by their high carbon sequestering potential (Jennerjahn and Venugopal, 2002). Globally, mangroves cover an area of about 1,37,760 km^2 (Giri et al., 2011), of which around 3.5% is in India amounting to a total area of 4921 km^2 (Forest Survey of India, 2017). In India, the state of Maharashtra contributes 6.2% of the total mangrove cover with an area of 304 km^2. Mumbai coast has 66 km^2 of mangroves. Management of the fast-declining mangrove ecosystem requires a comprehensive understanding of the structural complexity (Dislich and Pivello, 2002). Prior to forest management operations, biodiversity inventories are required to determine the nature and distribution of the species (Sagar et al., 2003).

Mangroves floristics along the Mumbai coast has been studied by many since 1905. However, the actual number of mangroves species, existing along the Mumbai coast is not known. For instance, Blatter (1905) provided a comprehensive account of mangroves of Mumbai coast and reported 14 species. Subsequently, Cooke (1903, 1908), in his book "Flora of the Presidency of Bombay"- vol. I and vol. II, listed 15 true mangrove species. *Avicennia alba* was reported by Cooke (1903, 1908) but was not included by Blatter (1905). Thereafter, Navalkar (1940, 1942, 1948,

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1951, 1953, 1956, 1959, 1973) and Navalkar and Bharucha (1948, 1950) reported on the detailed ecology, distribution and succession pattern of mangroves of Mumbai coast. All these publications indicate the degraded nature of mangroves along the Mumbai coast. Jagtap et al. (2001) reported the area of mangroves in Maharashtra to be 210 km^2, and noted the increasing anthropogenic stress on mangroves along the Mumbai coast. Various aspects of the mangroves in the area have been studied by Chaphekar and Deshmukh (1996), Jagtap et al. (2001), Kulkarni et al. (2010), Qureshi (1957), Vijay et al. (2005), and Vikrant et al. (2015). However, the vegetation structure of Mumbai mangroves has not been studied. Therefore, the present study was undertaken to understand the structural complexity and species composition of the mangrove forests of along the Mumbai coast, considering the potential for providing livelihood to local community and preserving the shoreline. Information derived from the present study will provide a more comprehensive perspective of the mangroves of the area and will contribute in formulation of location-specific strategic action plans.

2. Material and methods

2.1. Study area and data collection

Mumbai lies within the geographical location: 18°96′ N and 72°81′ E, with an average elevation of 10 to 15 m. It is a city of seven islands located in the 'Konkan' region along the west coast of India. The study was conducted at eight mangrove sites viz., Gorai (GOR), Versova (VER), Juhu (JUH), Bandra (BAN), Bandstand (BST), Sewri (SEW), Vikhroli (VIK) and Elephanta Island (ELE), along the Mumbai coast (Fig. 1). Field surveys were conducted from August 2015 to May 2016. At each site, multiple linear transects (100 m) were laid perpendicular to the water front with at least 50 m between adjacent transects. Quantitative data on mangrove vegetative structure was collected by laying quadrats (10 × 10 m) along the line transects. A total of 25 line transects were laid and in each line transect quadrats were examined at 0, 50 and 100 m (Table S1). However, in some places quadrats were restricted up to 50 m from the waterline. A total of 72 quadrats were sampled from all the sites. Within each quadrat, all mangroves were identified up to species level and were counted according to three maturity categories as described by Kathiresan and Ajmalkhan (2013), viz., trees (>4 m height), saplings (>1 m to ≤4 m height) and seedlings (plant ≤1 m height). Vegetation measurements viz., tree height and girth at breast height (GBH) were noted for all the trees and species-wise count data were collected for seedlings and saplings in each quadrat studied. From the above mentioned plant height measurement data, the regeneration status of all mangrove juveniles of plant with height <300 cm, were assessed by dividing them into three categories as Regeneration Class-I (<40 cm height), Regeneration Class-II (40–150 cm height) and Regeneration Class-III (150–300 cm height) (Kairo et al., 2002). Mangrove species were identified by using standard field guides like Kathiresan and Ajmalkhan (2013) and Tomlinson (1986). Flowers, fruits, and propagules of mangroves were photographed for confirmation. Species nomenclature primarily followed Tomlinson (1986) and identified species nomenclature was also confirmed with International Plant Names Index (IPNI).

2.2. Data analysis

The vegetation data were quantitatively analysed for abundance, density and frequency (Curtis and McIntosh, 1950). *Acanthus ilicifolius* was excluded in tree density calculation, as no individuals were observed to grow to more than 4 m in height. Importance Value Index (IVI) was determined from the sum of the relative frequency, relative density and relative abundance of the mangrove species (Misra, 1968). The relative dominance was calculated based on the basal area of individual trees, which was calculated as: basal area = $(GBH)^2/4\pi$. Apart from this, univariate measures viz., Shannon and Wiener diversity index (H') (Shannon and Wiener, 1963), Margalef's species richness (d) (Margalef, 1978), Pielou's evenness index (J') (Pielou, 1966), Simpson's dominance index (D) (Simpson, 1949), Complexity Index (Ic) (Holdridge, 1967; Pool et al., 1977) and Maturity Index Value (MIV) (Nabi and Rao, 2012) were determined. Variation pattern in community structure was evaluated by multivariate methods as a grouping analysis (Cluster) based on Bray–Curtis similarity index by using PRIMER v6 program. Mangrove species density data were square-root transformed to reduce the effect of high densities and used for PRIMER analyses.

3. Results

3.1. Species composition

A total of 10 true mangrove species, belonging to 5 families and 8 genera were recorded. Members of family Acanthaceae and Rhizophoraceae were the most dominant mangroves with 3 species each, followed by Lythraceae with 2 species. Versova Creek showed the highest diversity (10 species), followed by Gorai Creek (8 species) and the lowest number of species was recorded from Bandra (2 species; Table 1). Among the ten true mangrove species reported along the Mumbai coast, the distribution of *Avicennia marina* and *Sonneratia apetala* were more common than other mangrove species. All the reported species were in the Least Concern (LC) status, according to The IUCN Red List of Threatened Species (IUCN, 2017).

3.2. Structural features of mangroves

A total of 72 quadrats were studied and 3905 plants were enumerated. Of these, trees represented 11.7% (>4 m height), saplings (>1 m to ≤4 m height) and seedlings (≤1 m height) contributed 19% and 68.7%, respectively. The total tree density and basal area were found to be 635 individuals ha^{-1} and 10.98 m^2 ha^{-1}, respectively (Table 2). The highest tree density was noted at Elephanta Island (708 individuals ha^{-1}), followed by Vikhroli (700 individuals ha^{-1}), and the lowest tree density was reported from Gorai (325 individuals ha^{-1}). The basal area was quite high at Elephanta Island (28.23 m^2 ha^{-1}) and very low at Vikhroli (5.6 m^2 ha^{-1}) (Table 3). Among the 10 species, the highest tree density was observed for *A. marina* (493 individuals ha^{-1}) and density was less than 10 individuals ha^{-1} for other species (Table 2).

At all the sites, except Elephanta Island, *A. marina* contributed about 90% of the basal area and 50% of IVI, whereas in Elephanta Island *Sonneratia alba* was dominant and constituted 89% of basal area and 66% of IVI. On the whole, *A. marina* contributed 71% of basal area and 50% of IVI along the Mumbai coast. MIV varied between 58% and 26%. It was very high at Bandra and Vikhroli (58%) and very low at Versova (26%). Complexity Index (Ic) was high at Elephanta Island (4.56) (Table 3). MIV and Ic values of mangroves were 20.69% and 3.77, respectively (Table 4). GBH class distributions revealed that the mangroves stand of Mumbai city were dominated by trees with GBH of 20–40 cm, followed by 40–60 cm (Fig. 2). Tree height ranged between 4.1 and 11.0 m with average of 5.4 m, irrespective of species.

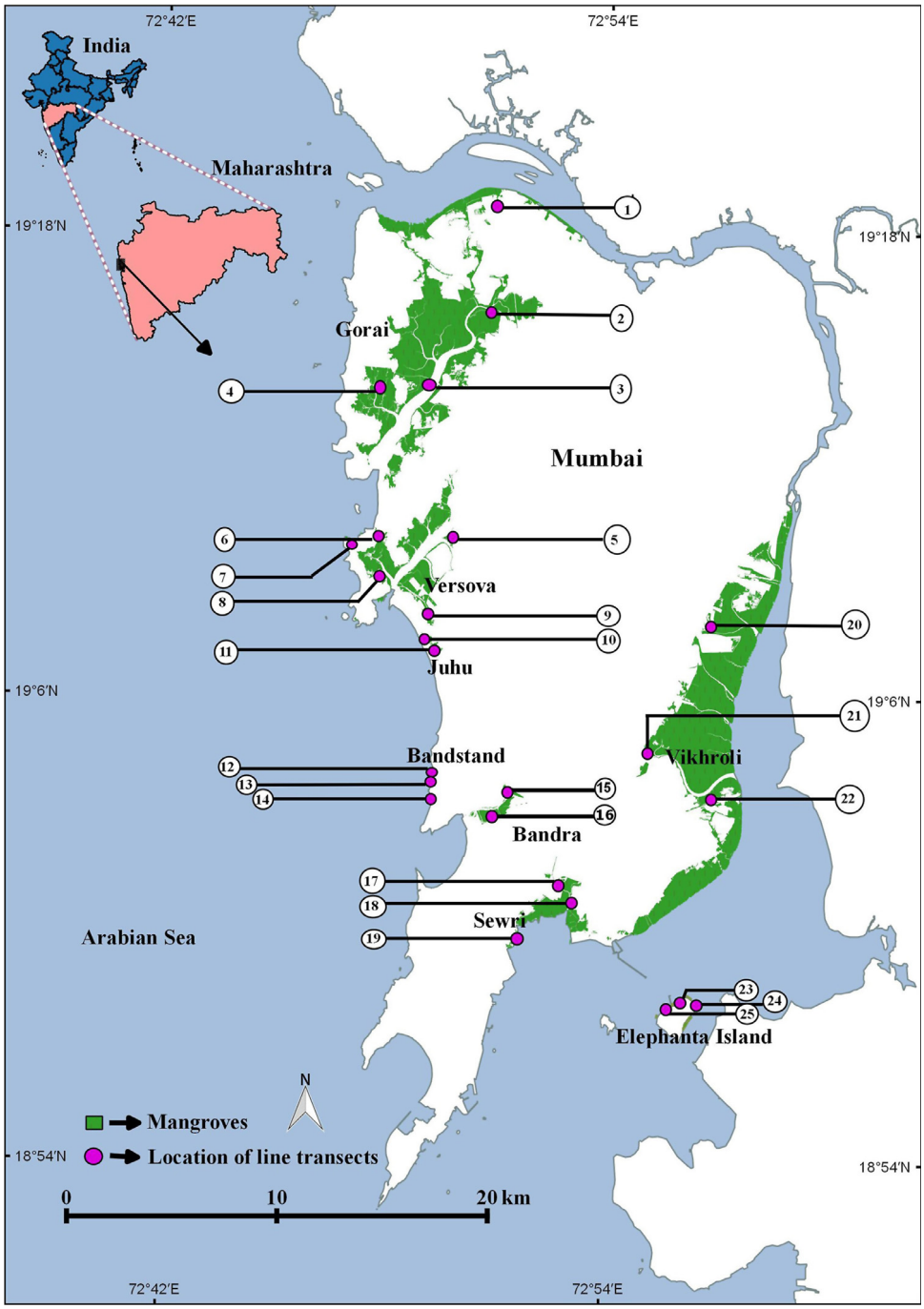

Fig. 1. Map of the study area depicting the survey sites and location of line transects. (see Supplementary Table S1 for names and geographical coordinates of line transects).

3.3. Diversity pattern

Shannon and Wiener diversity index for the whole Mumbai coast was 0.9 and Simpson index (1-D) was 0.39, indicating significantly less diversity in the mangroves as compared to normal range i.e. $H' = 1.5 - 3.5$ (Margalef, 1972). Further low values of species richness (1.08) and evenness index (0.39) indicate the monospecies dominance of mangroves (Table 4). Among the patches studied, Shannon and Wiener diversity index was recorded to be the highest at Gorai (1.02), followed by Vikhroli (0.95) whereas the lowest value occurred at Bandra (0.04). Simpson dominance index value was very high at Bandra (0.98) and it was very low at Vikhroli (0.47). The highest value of evenness index was observed at Vikhroli (0.59) and the lowest value was recorded at Bandra (0.06). Bray–Curtis cluster analysis under group average (Fig. 3) showed that the majority of sites were grouped together with 70% similarity, based on the similarity in species composition and density observed. The outliers viz., Versova and Elephanta Islands might be due to the occurrence of high species richness (10 species) and high basal area (28.23 m^2 ha^{-1}) respectively in comparison to the other sites.

3.4. Regeneration status

The total average density of juveniles was 4611 individuals ha^{-1} (Table 5). The total average densities of established juveniles viz., Regeneration Class II and Regeneration Class III were 1922 individuals ha^{-1} and 529 individuals ha^{-1}, respectively (Table 5). *A.*

Table 1
Distribution and red list categories of true mangrove species identified in the present study.

Family	Species	Name of the study sites								Red list category
		Gorai	Versova	Juhu	Bandra	Sewri	Vikhroli	Bandstand	Elephanta	
Acanthaceae	*Avicennia marina* (Forssk.) Vierh.	•	•	•	•	•	•	•	•	LC↓
	Avicennia officinalis L.	•	•							LC↓
	Acanthus ilicifolius L.	•	•	•		•	•			LC?
Myrsinaceae	*Aegiceras corniculatum* (L.) Blanco	•	•				•		•	LC↓
Rhizophoraceae	*Bruguiera cylindrica* (L.) Blume	•	•	•		•		•		LC↓
	Ceriops tagal (Perr.) C.B.Rob.	•	•							LC↓
	Rhizophora mucronata Lam.		•	•	•			•		LC↓
Euphorbiaceae	*Excoecaria agallocha* L.	•	•				•			LC↓
Lythraceae	*Sonneratia apetala* Buch.Ham.	•	•	•		•	•	•	•	LC↓
	Sonneratia alba Sm.		•					•	•	LC↓

• — denotes occurrence.
LC↓ — Least Concern with decreasing population trend.
LC? — Least Concern with unknown population trend.

Table 2
Forest structural characteristics (Tree density, Basal area and IVI %) of mangrove species along the Mumbai coast.

Species	Stand structure			
	Density (Individuals ha^{-1})	Basal area (m^2 ha^{-1})	Average height (m)	IVI (%)
Avicennia marina	493.05	7.85	5.45	49.93
Avicennia officinalis	2.77	0.11	6.00	2.46
Acanthus ilicifolius	0.00	0.00	–	13.96
Aegiceras corniculatum	2.77	0.02	4.15	4.16
Bruguiera cylindrica	1.38	0.01	4.20	4.17
Ceriops tagal	1.38	0.01	4.10	11.25
Rhizophora mucronata	1.38	0.00	4.10	3.26
Excoecaria agallocha	9.72	0.02	4.10	2.54
Sonneratia apetala	8.33	0.13	5.37	2.40
Sonneratia alba	113.88	2.83	5.71	5.81
Total	**634.66**	**10.98**		**100**

Table 3
Site wise structural parameters of mangrove survey sites along the Mumbai coast.

Name of the study site	No. of species	Density (Individuals ha^{-1})	Basal area (m^2 ha^{-1})	Diversity (H')	Richness (d)	Evenness (J')	Dominance (D)	Maturity index (%)	Complexity index (Ic)
Gorai	8	325	8.70	1.02	1.01	0.49	0.51	28.12	1.50
Versova	10	535	10.11	0.81	1.40	0.35	0.65	26.42	2.43
Juhu	5	550	9.50	0.22	0.72	0.14	0.91	33.33	1.32
Bandstand	4	467	8.90	0.17	0.61	0.12	0.93	30.56	0.86
Bandra	2	600	10.22	0.04	0.20	0.06	0.98	58.33	0.06
Sewri	4	662	8.02	0.46	0.43	0.33	0.74	50.00	1.18
Vikhroli	5	700	5.60	0.95	0.60	0.59	0.47	57.78	0.88
Elephanta Island	4	708	28.23	0.31	0.63	0.22	0.86	43.75	4.56

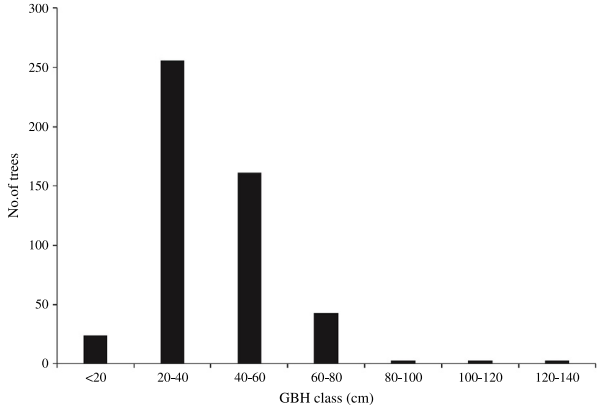

Fig. 2. Distribution of Girth at Breast Height (cm) of mangrove trees along the Mumbai coast.

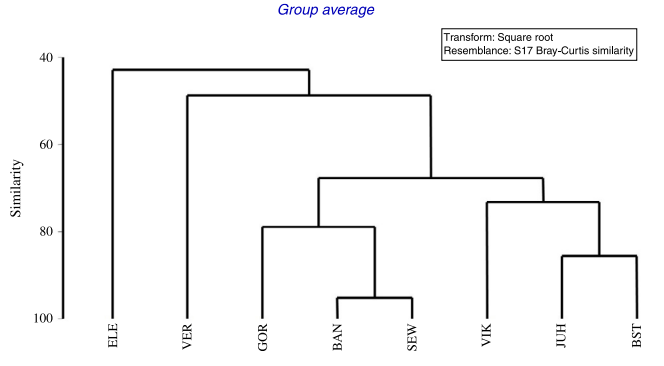

Fig. 3. Dendrogram showing similarity among the surveyed sites along the Mumbai coast.

marina represented 75.63% of total juveniles, followed by *Acanthus ilicifolius* (13.76%) and *Ceriops tagal* (3.79%) (Table 5). Density of RC I was lower than the RC II and RC III for all the species except, *A. marina*, indicating high regeneration potential of *A. marina* than other mangrove species.

Table 4
Univariate measures of mangrove stands along the Mumbai coast.

Parameter	Value
Maturity index (%)	20.69
Complexity index (Ic)	3.77
Species richness (S)	10
Mean species richness	1.25
Margalef's richness index (d)	1.08
Shannon and Wiener index (H')	0.90
Simpson index (D)	0.61
Pielou's eveness index (J')	0.39

4. Discussion

4.1. Species composition

The coastal area of Maharashtra is known for its rich mangrove diversity along the west coast of India. Due to increased anthropogenic activities, composition of mangrove flora has been adversely affected that led to the degradation of coastal creeks and mangroves (Dwivedi, 1973; Nammalwar, 2008). The total number of species reported in the present study were low compared to the contemporary studies (Table 6). In contrast to earlier studies, four species viz., *Lumnitzera racemosa*, *Kandelia candel*, *Sonneratia caseolaris* and *Avicennia alba* could not be found in the present study. It is pertinent to note that in the past *S. acida* was used as a synonym for both *S. alba* and *S. caseolaris*. Blatter (1905) and Cooke (1903) reported *S. acida* from Mumbai coast, based on latter one's description, i.e., dark rose petals and thus it is well apparent that they have treated *S. caseolaris* as *S. acida*. But in subsequent studies, only *S. alba* and *S. apetala* were reported from Mumbai coast and distribution of *S. caseolaris* was restricted to southern districts of Maharashtra coast (Chavan, 2013). Blatter (1905) and Cooke (1903) reported *L. racemosa* from Mumbai coast. However, Navalkar (1951) noted that *L. racemosa* was present in Bandra region, till the year 1934 but after that, it was not reported from this coast. This indicates the extirpation of *L. racemosa* from Mumbai coast. Similarly, *A. alba* reported by Blatter (1905) and Cooke (1903), was identified as *A. marina* var. *acutissima* by Moldenke (1960). Hence, the occurrence of *A. alba* along the Mumbai coast needs to be confirmed through extensive taxonomical studies.

Distribution of mangrove species depends on various environmental parameters like temperature, salinity, tidal pattern and freshwater inflow, which are specific to each habitat (Duke et al., 1998). Due to release of sewage water, the concentration of nutrients, heavy metals and Polycyclic Aromatic Hydrocarbons (PAHs) is persistently increasing in most creeks along the Mumbai coast (Datta, 2012; Kulkarni et al., 2010; Navalkar, 1951; Sahu and Bhosale, 1991; Singh et al., 2007; Sukhdhane et al., 2015). Kantharajan et al. (2017), recently reported the occurrence of pollution indicating molluscan species like *Neripteron violaceum* and members of Ellobidae family (*Cassidula* and *Melampus*), in the mangrove ecosystems of Mumbai. Further, salinity in the creeks of Mumbai coast remain >31 ppt year round (Kulkarni et al., 2010) due to reduced inflow of land runoff and salt production in the upstream regions. Absence of low saline tolerant species like *S. caseolaris*, *L. racemosa* and *K. candel* is also indicative of increased tidal influence and reduced freshwater inflow. Prevalence of high saline conditions are conducive for growth of high salt tolerant species like *A. marina* and obligate halophytes like *Sesuvium portulacastrum*, *Suaeda maritima* and *Suaeda nudiflora*. During our survey, we observed the spread of above said species in study sites like Juhu, Gorai and Vikhroli. Thus, the dominance of *A. marina* and poor abundance and diversity of mangroves along the Mumbai coast indicate highly stressed environment.

4.2. Structural features of mangroves

Total tree density and basal area for the whole Mumbai coast were 635 individuals ha^{-1} and 11.16 m^2 ha^{-1}, respectively. *A. marina* alone contributed 78% and 71% of tree density and basal area, respectively. Further, *A. marina* represented 50% of the IVI. This shows the mono-species dominance of mangroves along the Mumbai coast. Recently, Shindikar et al. (2009) also reported the dominance of *A. marina* in mangrove forests of Thane Creek along the Mumbai coast. The dominance of *A. marina* is common along the Arabian Sea bordering countries and the northwest coast of India. The prevailing high saline environment might be the cause of dominance of *A. marina* in the West Coast of India (Saenger et al., 2002; Sawale and Thivakaran, 2013).

Pristine mangrove forest with minimal impacts have been shown to have a basal area of >25 m^2 ha^{-1} (Kauffman et al., 2011; Komiyama et al., 2008), secondary forests (forests regenerated after the disturbances of the original vegetation) has been found to have basal area of around 15 m^2 ha^{-1} (Cavalcanti et al., 2009; Komiyama et al., 2008), and disturbed forest show basal area of <10 m^2 ha^{-1} (Komiyama et al., 2008). Thus, the low basal area recorded for mangroves along the Mumbai coast indicate the disturbed nature of mangrove forest with low structural development. Earlier reports also revealed the anthropogenic disturbances on the mangroves of Mumbai coast (Chatterjee, 2015a, b; Kairo et al., 2002; Lewis, 2013; Untawale, 1986). Furthermore, the highest number of individuals was found to be distributed in the 20–40 cm GBH class, indicating that the mangrove community is still in a growing phase. Thivakaran et al. (2003) observed similar result in *Avicennia* stands in the Gulf of Kutch mangroves. The observed low MIV also indicate the immature nature of the mangroves along the Mumbai coast.

The Complexity Index (Ic) is often used for quantitative description of the structural complexity of the tropical vegetation (Pool et al., 1977). It is a result of cumulative contribution of total number of species, the density, basal area and the tree height. The estimated Ic values for Mumbai mangroves were lower than the reported values in earlier studies (Amarasinghe and Balasubramaniam, 1992; Fromard et al., 1998; Joshi and Ghose, 2014; Pool et al., 1977; Upadhyay and Mishra, 2014). The Ic value directly reflects the variation in tree height, density and basal area of the forest stand. In general, stunted growth, low basal area and high density are indicative of least complex mangrove stands (common in arid regions), whereas tall canopy, high basal area, and lower stem density are indicative of highly complex mangrove stands (common in wet and humid region) (Smith, 1992). Singh et al. (1990) and Singh and Odaki (2004) reported Ic values of 6.9 to 14.1 for disturbed and 87.1 to 260 for undisturbed mangroves of Andaman Islands of India. Thus the low Ic value (0.06–4.56), recorded in the present study, indicate the low structural development and disturbances in Mumbai mangroves.

This study was not intended to assess the zonation pattern of mangroves; but based on our *in situ* observation, it may be noted that the zonation pattern is in accordance with suggestion of Vijay et al. (2005). *A. marina* dominated the water front area, followed by *Rhizophora mucronata*; *Bruguiera cylindrica* in the next zone with intermittent distribution of *Ceriops tagal* and *Aegiceras corniculatum*. A combination of *Excoecaria agallocha* and *Acanthus ilicifolius* formed the back mangrove zone. *S. alba* dominated the water front sea margin wherever it was observed in the field.

4.3. Diversity pattern

The diversity index is intended to measure the biodiversity of an ecosystem and facilitate understanding, conservation and utilization of living resources by creating a single annotated index of

Table 5
Juvenile density of mangroves along the Mumbai coast.

Species	Regeneration Classes (RC)						Total	
	RC I (0–40 cm)		RC II (>40–150 cm)		RC III (>150–300 cm)			
	Individuals ha^{-1}	%	Individuals ha^{-1}	%	Individuals ha^{-1}	%	Individuals ha^{-1}	%
Avicennia marina	1988.89	57.03	1144.44	32.82	354.17	10.16	3487.50	75.63
Avicennia officinalis	0.00	0.00	1.39	9.09	13.89	90.91	15.28	0.33
Acanthus ilicifolius	166.67	26.26	451.39	71.12	16.67	2.63	634.72	13.76
Aegiceras corniculatum	0.00	0.00	47.22	56.67	36.11	43.33	83.33	1.80
Bruguiera cylindrica	1.39	1.72	54.17	67.24	25.00	31.03	80.56	1.74
Ceriops tagal	0.00	0.00	168.06	96.03	6.94	3.97	175.00	3.79
Rhizophora mucronata	2.78	6.45	30.56	70.97	9.72	22.58	43.06	0.93
Excoecaria agallocha	0.00	0.00	2.78	10.53	23.61	89.47	26.39	0.57
Sonneratia apetala	0.00	0.00	6.94	35.71	12.50	64.29	19.44	0.42
Sonneratia alba	0.00	0.00	15.28	33.33	30.56	66.67	45.83	0.99

Table 6
Species composition of true mangroves along the Mumbai coast according to various authors.

Sl. No.	Mangrove species	Blatter (1905)	Cooke (1903, 1908)	Navalkar (1951)	Qureshi (1957)	Chaphekar and Deshmukh (1996)	Vijay et al. (2005)
1	*Acanthus ilicifolius*	•	•	•	•	•	•
2	*Aegiceras corniculatum* (= *A. majus*)	•	•	•	•	•	•
3	*Avicennia alba*		•	•	•		
4	*Avicennia marina*					•	•
5	*Avicennia officinalis*	•	•	•	•	•	
6	*Bruguiera cylindrica* (= *B. caryophylloides*)	•	•		•	•	•
7	*Bruguiera gymnorhiza*	•	•	•	•		
8	*Bruguiera parviflora*	•	•		•		
9	*Ceriops tagal* (= *C. candolleana*)	•	•	•	•	•	•
10	*Cynometra ramiflora* (= *C. iripa*)				•		
11	*Excoecaria agallocha*	•	•	•	•	•	
12	*Lumnitzera racemosa*	•	•	•	•		
13	*Rhizophora conjugata*	•	•		•		
14	*Rhizophora mucronata*	•	•	•	•	•	•
15	*Sonneratia alba*					•	
16	*Sonneratia apetala*	•	•	•	•	•	•
17	*Sonneratia caseolaris*	•	•	•	•		
18	*Kandelia candel* (= *K. rheedii*)	•	•	•	•	•	
19	*Xylocarpus granatum* (= *Carapa obovata*)	•	•		•		
Total no. of species		**15**	**16**	**12**	**17**	**11**	**7**

• — denotes occurrence.

biological collections. In general, Shannon's index falls in the range of 1.5–3.5 for a good diversified area and it is considered to be zero when there is no diversity (Margalef, 1972). The diversity pattern of mangrove species we studied, was found to be in agreement with that described by Kulkarni et al. (2010). The low values of Shannon and Wiener index (0.9), Simpson dominance index (0.61) and Pielou's evenness index (0.39) indicate the low diversity and uneven distribution of mangroves species along the Mumbai coast.

4.4. Stages of regeneration of mangroves

Seedling recruitment and survival are the critical factors considered in tree population dynamics, which determine the crop quality and forest stand productivity (Burns and Ogden, 1985; Krauss et al., 2008; Srivastava and Bal, 1984). Srivastava and Bal (1984) proposed that, a minimum of 2500 well-distributed seedlings ha^{-1} are required for adequate natural regeneration. Except for *A. marina*, all other mangroves species recorded from Mumbai coast, had low seedling density (<2500 ha^{-1}), indicating the reduced regeneration potential of these species. Kamruzzaman et al. (2017) concluded that the physical, chemical and/or biological conditions are the important determinants of mangrove species natural regeneration. Thivakaran et al. (2003) also reported low regeneration potential of species other than *A. marina* in the Gulf of Kutch and noted that non-availability of propagules could be the determinant for poor diversity in Gulf of Kutch. The present findings also supported the above statement.

5. Conclusion

The structure of a mangrove forest is influenced by the magnitude and periodicity of tides, nutrients, monsoon periods and prevailing stressors. Since the influence of these factors vary widely over geographic regions, mangrove stands exhibit wide regional and local variation in their structural characteristics. Hence, understanding the local level forest structure is highly essential for their management. Mangrove areas along the Mumbai coast have been threatened by various anthropogenic activities viz., dumping garbage and disposal of sewage as well as overexploitation for salt, fishing, navigation, and recreational activities. Low species diversity and structural complexity recorded in the study indicates the degraded nature of the mangroves along the coast. In addition, the prevalence of high saline conditions along the Mumbai Creeks threatened the low saline tolerant species like *S. caseolaris*, *K. candel*. Though a high saline condition is conducive for the growth of *A. marina*, monospecies dominance reduces the ecological and economic services offered by mangroves. Lack of understanding of spatial distribution and habitat requirements of mangrove species is the major impediment in conservation efforts. Hence, the results from the current study provide baseline data for proper conservation and management of mangroves along the Mumbai coast.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2018.02.011.

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